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WIREWORM-INFESTATION TRENDS ACCOMPANYING CERTAIN CROP ROTATIONS IN THE PACIFIC NORTHWEST

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The Bureau of Entomology and Plant Quarantine in Cooperation with the Idaho Agricultural Experiment Station

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INTRODUCTION

A study of crop rotations and cultural practices in their relationship to wireworm infestations was begun at Parma, Idaho, in 1930, as a part of the Pacific Northwest wireworm project. The objective was to determine what cultural methods would result in the greatest reduction in wireworm numbers, as previous field observations had indicated that wireworm infestations vary in intensity under different methods of farming. Small experimental plots were determined upon, since their use would permit the measurement of fluctuations in wireworm numbers, and at the same time demonstrate the effect of various crop and soil conditions on wireworm survival; and a series of such plots was laid out in the spring of 1931 in a field infested with wireworms. Crop rotations in use by truck farmers in the irrigated sections of the Pacific Northwest were selected for study. The wireworm infestation of each plot was determined at the beginning of the experiments and annually thereafter.

Certain trends of wireworm infestations which have been observed in these plots during the last four seasons are so obvious that the conclusions drawn from them appear of considerable practical importance. The long life cycle of wireworms, ranging from 2 to 5 years, together with the necessity for repeating the crop rotations, precludes

[1] The investigations of which this circular reports the preliminary results are being conducted under the direction of M. C. Lane, in charge of the Pacific Northwest wireworm project, to whom acknowledgments are due for advice and suggestions and for criticism of the manuscript. The counsels of Claude Wakeland, entomologist, and of R. E. Bell, formerly soil technician, of the Idaho Agricultural Experiment Station, are gratefully acknowledged. The writers also give credit for assistance rendered them by E. W. Jones, who rearranged the data and checked the significance of the means by use of Fisher's t test.

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any present attempt to make final and complete recommendations for control based on experiments thus far conducted. It is hoped, however, that the results reported herein will provide information of value to farmers of the Pacific Northwest in combating wireworms.

PLOTS AND METHODS OF SAMPLING

The experiments are being conducted on a 5-acre tract of land of volcanic-ash origin with a high percentage of silt and clay. This area is divided into 21 plots, each measuring 50 by 150 feet and having an area of approximately one-sixth of an acre. The plots are separated by alleys 6 feet in width which are kept free of weeds by cultivation. All crops, with the exceptions which will be noted, have been grown under irrigation, since the average annual precipitation of this section is only 7.48 inches. The sugar-beet wireworm (*Limonius californicus* Mann.) is the predominating species under observation in these experiments, and the Pacific coast wireworm (*L. canus* Lec.) comprises about 10 percent of the infestation.

The numbers of wireworms on these plots are determined annually from soil samples examined by the sifting method, a motor-driven sifting machine being utilized for this purpose. The soil is passed successively through screens having 4, 12, and 18 meshes to the linear inch. The adults and larger larvae are found on the 12-mesh screen, while about 95 percent of the smaller larvae which pass through this are found on the 18-mesh screen beneath. By extensive sampling experiments it has been determined that, with plots of this size and with populations within the range found in these plots, 25 samples from each plot, each sampling the soil of 1 square foot to a depth of 18 inches, are sufficient to indicate significant changes in wireworm numbers. This sampling is done during the months from September to April, inclusive, in order that the beetles may be found before they emerge from the soil and that the larvae which hatched during the preceding spring may have attained a full season's growth. Each plot is sampled at approximately the same date in each successive year.

CROP ROTATIONS STUDIED

Six crop sequences, in common usage locally, were chosen for study in order that the results derived might be readily checked against the agricultural practices on the irrigated farms of the Pacific Northwest. The rotations as originally planned were as follows:

Rotation A. Alfalfa 4 years, potatoes 2 years, red clover 2 years, potatoes 2 years.
Rotation B. Alfalfa 3 years, potatoes 2 years.
Rotation C. Red clover 2 years, potatoes 1 year.
Rotation D. Red clover 2 years, potatoes 2 years, alfalfa 2 years, potatoes 2 years.
Rotation E. Corn 1 year, potatoes 1 year, beans 1 year.
Rotation F. Mixed grass pasture 4 years, potatoes 2 years.

Certain of the rotations planned soon resulted in so great an increase in wireworms that it became apparent that it would be impractical to grow the scheduled crops. Changes were made in these rotations, therefore, and various cultural practices of possible value in wireworm control have been introduced. Seven studies were made, each of which constituted an experiment in which one of the rotations or other planting scheme was studied and, as far as practical, was carried

on as originally planned. The details of each experiment and the changes that were found desirable in the original rotation will be explained under the discussion of the results obtained during the first 4 years. The experiments are being tested in triplicate to increase the accuracy of the results.

The trends in wireworm populations thus far observed in the plots are shown in tables 1 to 3 and 5 to 7, and summarized for the entire study in table 8. The infestation for each plot is expressed as the mean number of larvae found in each of the 25 soil samples.

EXPERIMENTS 1 AND 2

The part of rotation A thus far carried out differs from rotation B only in that the alfalfa continues 4 years in the first and 3 years in the second. This was compensated for in the plan by the substitution in rotation A of 2 years of red clover for the alfalfa every other seeding. Sweetclover may prove satisfactory to use instead of the red clover. Thus far the effects of the continuous growing of alfalfa are all that can be reported (tables 1 and 2). It has been found that low wireworm numbers not only fail to decrease in alfalfa ground, but that they undergo a small significant increase during a period of years. Rapid increase of wireworms is, however, inhibited in alfalfa fields that are reasonably free from weeds. This result is believed to be largely due to the fact that this crop has a tendency to remove moisture rapidly, resulting in a hard, dry condition of the soil unfavorable to all stages of the wireworm species involved in the tests.

TABLE 1.—*Average number of wireworms per square foot found at the close of each season in soil planted to alfalfa, Parma, Idaho*

Plot no.	Wireworms per square foot found in the soil				Difference in infestation			
	1931	1932	1933	1934	Between 1933 and 1931	Divided by error	Between 1934 and 1931	Divided by error
	Number	*Number*	*Number*	*Number*	*Number*		*Number*	
1	[1]0.6±.2	1.1±.2	1.1±.2	2.4±.4	0.5±.28	1.8	1.8±.44	4.1
12	1.0±.2	.8±.2	3.2±.6	2.5±.3	2.2±.63	3.5	1.5±.36	4.2
15	.7±.2	1.2±.4	2.1±.3	2.8±.5	1.4±.36	3.9	2.1±.53	4.0
Average	.8±.12	1.0±.16	2.1±.23	2.6±.23	1.3±.26	5.0	1.8±.26	6.9

[1] The standard error and not the probable error is shown after the ± in tables 1 to 3 and 5 to 7.

TABLE 2.—*Average number of wireworms per square foot found at the close of each season in soil planted to potatoes, followed by 3 years of alfalfa, Parma, Idaho*

Plot no.	Wireworms per square foot found in soil planted to—				Difference in infestation			
	Potatoes, 1931	Alfalfa, 1932	Alfalfa, 1933	Alfalfa, 1934	Between 1933 and 1932	Divided by error	Between 1934 and 1932	Divided by error
	Number	*Number*	*Number*	*Number*	*Number*		*Number*	
2	0.6±.1	0.9±.2	2.5±.5	2.5±.3	1.6±.53	3.0	1.6±.36	4.4
13	1.6±.4	2.0±.4	3.3±.4	2.5±.3	1.3±.56	2.3	.5±.5	1.0
16	.5±.1	.8±.2	1.9±.3	2.8±.3	1.1±.36	3.0	2.0±.36	5.5
Average	.9±.14	1.2±.16	2.6±.23	2.6±.17	1.4±.28	5.0	1.4±.23	6.1

EXPERIMENTS 3 AND 4

The next two rotations as planned differed primarily in that with rotation D a 2-year period in alfalfa alternates with the red clover. Red clover has been a popular crop in many districts. It affords an opportunity for soil improvement, the production of hay, and high monetary returns from seed. The use of this crop is generally avoided, however, by experienced truck farmers on account of its susceptibility to wireworm infestation, as verified by the results shown in table 3. The red clover rotations have developed large populations of wireworms, and these have persisted for several seasons after plowing under the red clover. In this connection it should be mentioned that part of plot 14 in table 3 and most of plot 7 in table 6 were plowed out of red clover at the beginning of these experiments. This explains the high initial populations of these two plots. It appears improbable that red clover can be grown successfully in rotations with potatoes or other crops which are especially susceptible to wireworm injury. Inasmuch as the underlying purpose of this study is to determine the rotations that are most feasible from the standpoint of keeping wireworms at a minimum, it has seemed desirable at times to discontinue the growing of red clover and to substitute sweetclover.

TABLE 3.—*Average number of wireworms per square foot found at the close of each season in soil planted as indicated, Parma, Idaho*

Plot no.	Red clover, 1931	Red clover, 1932	Sudan grass, 1933	Wheat,[1] 1934	Difference in infestation					
					Between 1932 and 1931	Divided by error	Between 1933 and 1932	Divided by error	Between 1934 and 1933	Divided by error
	Number	*Number*	*Number*	*Number*	*Number*		*Number*		*Number*	
3	1.3±.3	5.2±.1	18.1±1.2	7.5±.5	3.9±.3	13.0	12.9±1.2	10.7	−10.6±1.3	8.1
14 [2]	7.3±.8	6.2±.2	10.2±1.2	4.8±.7	−1.1±.82	1.3	4.0±1.2	3.3	−5.4±1.4	3.9
17	1.5±.3	3.0±.5	11.0±1.1	4.7±.5	1.5±.58	2.6	8.0±1.2	6.6	−6.3±1.2	5.2
Average	3.4±.3	4.8±.18	13.1±.67	5.7±.33	1.4±.34	4.1	8.3±.69	12.0	−7.4±.74	10.0

Plot no.	Red clover, 1931	Red clover, 1932	Wheat, 1933	Potatoes, 1934	Difference in infestation			
					Between 1932 and 1931	Divided by error	Between 1933 and 1932	Divided by error
5	3.6±.5	5.8±.8	7.4±.8	5.3±.8	2.2±.94	2.3	1.6±1.13	1.4
8	1.4±.2	3.6±1.0	16.1±1.3	8.1±.9	2.2±1.01	2.2	12.5±1.6	7.8
19	1.3±.3	3.3±.7	4.7±.7	5.9±1.0	2.0±.76	2.6	1.4±.99	1.4
Average	2.1±.21	4.2±.48	9.4±.55	6.4±.52	2.1±.51	4.1	5.2±.72	7.2

[1] Without irrigation.
[2] Plot 14 was plowed out of red clover when the series of experiments began.

In some cases (table 3) where infestations have become too high to permit the growing of the scheduled crops, wheat has been grown with no irrigation in an attempt to dry the soil sufficiently to kill the wireworms. Sudan grass was also introduced in rotation C. In experiment 3 during 1934 over 50 percent decrease in the number of wireworms followed the growing of wheat without any irrigation. The remaining infestations, however, are still too large for the planting of potatoes with any assurance of freedom from severe wireworm injury.

ADDITIONAL EXPERIMENT ON ROTATIONS C AND D

There are included in table 4 some data which should be considered before leaving the discussion of rotations C and D. Red clover, sweetclover, and alfalfa were compared in a study to determine host-plant preferences of wireworms. Individual 1-year-old plants of these legumes were interplanted every 18 inches in rows 2 feet apart in a special plot. At the end of 2 months the plants were dug out and examined, with the results shown in table 4. Red clover appeared decidedly more subject to wireworm attack than either alfalfa or sweetclover, which were about equally infested. Interest in sweetclover has developed because of the apparent need of some crop to be used as a possible substitute for red clover in building up the soil for the following crop. Plot tests will evidently need to be made, however, before the effect of sweetclover on wireworm infestations under field conditions can be definitely determined.

TABLE 4.—*Wireworms found on red clover, sweetclover, and alfalfa plants, Parma, Idaho*

Crop	Plants	Plants infested		Total wireworms	Average wireworms per plant
	Number	*Number*	*Percent*	*Number*	*Number*
Red clover	83	40	48.2	128	3.2
Sweetclover	87	18	20.7	23	1.3
Alfalfa	88	21	23.9	26	1.2

EXPERIMENT 5

The areas continuously planted to late truck crops are represented by rotation E. Their soil fertility is maintained by the addition of fertilizers, mainly barnyard manure. They are planted to row crops which permit clean cultivation of the ground during the period of adult click beetle activity. Maintenance of a dust or dry-soil mulch during the period from the middle of April to the first of June will, it is believed, have a tendency to prevent the beetles from depositing eggs. The planting of late potatoes can often be deferred until June 1 or later, but at times it may be necessary to plant somewhat earlier than this date. The dry mulch is sometimes destroyed by rains, but a little care during most seasons will make it possible to maintain this dusty condition during most of the period of beetle flight. It will be noted from table 5 that the wireworm infestations in plots 6 and 20 have not changed materially throughout the 4-year period. These results are contrary to the belief, prevalent in the irrigated districts of the Pacific Northwest, that clean cultivation favors the increase of wireworm populations.

TABLE 5.—*Average number of wireworms per square foot found at the close of each season in soil planted to late truck crops and wheat, Parma, Idaho*

Plot no.	1931		1932		1933		1934	
	Crop	Wireworms per square foot	Crop	Wireworms per square foot	Crop	Wireworms per square foot	Crop	Wireworms per square foot
		Number		*Number*		*Number*		*Number*
6	Corn	4.6±0.5	Potatoes	4.2±0.7	Wheat	4.1±0.5	Corn	3.6±0.6
9	Peas	1.6± .5	do	2.9± .5	do	3.4± .4	do	5.5± .8
20	Beans	1.1± .3	do	.6± .2	do	1.3± .2	do	2.1± .6
Average		2.4± .25		2.6± .29		2.9± .22		3.7± .39

EXPERIMENT 6

Rotation F called for 4 years of grass pasture followed by 2 years of potatoes. Farmers have believed that pasture conditions are unfavorable for egg-laying by the wireworm adults on irrigated land. The nonleguminous pasture is a heavy-yielding mixture [2] composed of bromegrass, perennial ryegrass, and meadow fescue. A dense sod has been formed by these grasses, and the condition is in all respects comparable to a permanent pasture. This pasture crop apparently prevents the wireworm infestation from increasing (table 6). In plot 7 of this rotation, which was formerly in red clover, there was a pronounced reduction in the number of wireworms. In no instance, however, was there a sufficient reduction during the 4-year period to render the outlook entirely hopeful for the potatoes scheduled to follow the pasture. At the time of the annual soil siftings the presence of new-brood wireworms has been noted in these plots. This indicated that the beetles do lay eggs in sod ground. The corrugations necessary for ditch irrigation may offer more opportunity for oviposition than is to be found in pastures which can be irrigated by flooding.

TABLE 6.—*Average number of wireworms per square foot found at the close of each season in soil in grass pasture, Parma, Idaho*

Plot no.	Average wireworms per square foot			
	1931	1932	1933	1934
	Number	*Number*	*Number*	*Number*
7 [1]	6.3±0.6	5.4±0.8	4.7±0.5	3.2±0.5
10	[2] 1.2± .8	2.0± .3	1.5± .2	1.9± .3
21	1.9± .6	1.4± .3	1.7± .3	1.9± .4
Average	3.1± .39	2.9± .30	2.6± .20	2.3± .23

[1] Plot 7 had been in red clover in 1930.
[2] Plot 10 was planted to potatoes in 1931.

EXPERIMENT 7

In another series of plots, not originally designed as a rotation, it was necessary to provide for the planting of various areas to sugar beets. The remainder of the ground set aside for this series has been cultivated as a vegetable garden. The principal effort has been to keep down the weeds and to provide moisture for the growing crops. The sugar beets and certain of the other crops have been planted early. Little effort has been made to reduce the opportunities for reinfestation. The result, as indicated in table 7, has been a slow but significant increase in wireworm population. These conditions, even more so than those of rotation E, were expected to result in a rapidly increased infestation. The belief that cleanly cultivated crops lead to rapidly increasing numbers of wireworms has not thus far been substantiated by the results obtained. The rapidly developed infestations often observed are evidently caused by unusual conditions of wireworm survival such as are found when red clover is included in the rotation.

[2] This mixture was developed by the Idaho Agricultural Experiment Station and was observed at the Caldwell substation.

TABLE 7.—*Average number of wireworms per square foot found at the close of each season in soil planted to sugar beets, sweetclover, and garden truck, Parma, Idaho*

Plot no.	1931		1932		1933	
	Crop	Wireworms per square foot	Crop	Wireworms per square foot	Crop	Wireworms per square foot
		Number		*Number*		*Number*
4	Sugar beets	2.0±0.4	Sugar beets	1.4±0.3	Sugar beets	2.6±0.5
11	do	1.6± .4	Cantaloups	1.4± .2	Potatoes	2.6± .5
18	Garden	.5± .1	Garden	1.0± .2	Onions	3.6± .8
Average		1.4± .19		1.3± .14		2.9± .35

Plot no.	1934		Differences between 1934 and 1931	Difference divided by error
	Crop	Wireworms per square foot		
		Number	*Number*	
4	Sugar beets	3.5±0.8	1.5±0.89	1.7
11	Sweetclover	3.0± .3	1.4± .50	2.8
18	do	4.7± .8	4.2± .86	4.9
Average		3.7± .39	2.3± .43	5.3

DISCUSSION

The averages of the larval population for the seven experiments are summarized in table 8. The outstanding points to be observed are the rapid increases in wireworms with experiments 3 and 4, the plots planted to red clover; the sudden decrease in the number of wireworms in the plots of experiment 3 in 1934, when wheat was grown without irrigation; and the nearly stationary population with clean cultivation (experiment 5). Experiments 1 and 2 (alfalfa) and experiment 7 (sugar beets, etc.) show gradual and significant increases, but the numbers still remain little, if any, above the averages for the district. The indications are that only unusual conditions cause extremely high or extremely low wireworm infestations. Such unusual conditions, whatever they may be, are produced by growing red clover or by drying the soil through an entire season by growing unirrigated wheat. The planting of red clover is the outstanding factor thus far found to favor increase of wireworm numbers. Consequently the use of this crop in rotations should be avoided whenever farm planning will permit the substitution of a crop less favorable to the insect.

It is important to prevent high populations becoming established, as they have a tendency to continue at a high level for many seasons.

Normally, any increase or decrease in wireworm numbers appears to be gradual. Very low populations exhibit a tendency to increase slowly, while unusually high populations decrease gradually under the majority of the conditions encountered. The heavy mortality in the egg and small larval stages, supplemented by the normal die-off throughout the long life cycle, permits but slow fluctuations, under usual conditions.

TABLE 8.—*Crop rotations and average wireworm populations in experiments 1 to 7, at Parma, Idaho*

Experiment no.	1931 crop	Wireworms per square foot	1932 crop	Wireworms per square foot	Increase or decrease over previous year [1]
		Number		*Number*	*Percent*
1	Alfalfa	0.8	Alfalfa	1.0	25
2	Potatoes	.9	do	1.2	33
3	Red clover	3.4	Red clover	4.8	41
4	do	2.1	do	4.2	100
5	Late truck	2.4	Potatoes	2.6	8
6	Pasture	3.1	Pasture	2.9	−6
7	Early truck	1.4	Early truck	1.3	−7

Experiment no.	1933 crop	Wireworms per square foot	Increase or decrease over previous year [1]	1934 crop	Wireworms per square foot	Increase or decrease over previous year [1]
		Number	*Percent*		*Number*	*Percent*
1	Alfalfa	2.1	110	Alfalfa	2.6	24
2	do	2.6	116	do	2.6	0
3	Sudan grass	13.1	173	Wheat [2]	5.7	−56
4	Wheat	9.4	124	Potatoes	6.4	−32
5	do	2.9	12	Corn	3.7	27
6	Pasture	2.6	−10	Pasture	2.3	−12
7	Early truck	2.9	123	Early truck	3.7	27

[1] Minus sign denotes decrease. [2] Not irrigated in 1934.

NUMBERS OF ADULTS

A factor influencing the fluctuations in wireworm infestations is the number of adult beetles present and laying eggs during the flight season. This is one factor which it has not been possible to control in the present study with the limitations of experimental plots. The infestation in a given experimental plot is more subject to the influence of adult migrations from surrounding plots than would be that of a commercial field to migrations from other similar fields. For example, the alfalfa plots have shown wireworm increases apparently exceeding the expectancy that could be attributable to adults emerging from these plots and depositing their eggs therein. In table 9 is shown the variation in numbers of beetles which emerged from given infestations under different crops in the course of these plot studies. It will be noted that there have been several times as many beetles produced following a season in certain crops as were found following others. A noteworthy beetle emergence is frequently observed following crops such as potatoes and sugar beets. Very few beetles emerged from the alfalfa or from pasture.

TABLE 9.—*Number of click beetles (adults of wireworms) produced under different crop conditions*

Crop	Plots	Samples	Average square-foot infestation of larvae, previous year	Total wireworms found		Ratio of larvae to adults
				Larvae	Adults	
	Number	*Number*	*Number*	*Number*	*Number*	
Sugar beets	5	125	3.0	375	68	5.5
Potatoes	10	250	3.9	975	148	6.6
Red clover	10	250	2.6	650	32	20.3
Wheat (not irrigated)	9	225	6.0	1,350	49	27.5
Alfalfa	21	525	1.6	840	17	49.4
Pasture	9	225	3.5	788	15	52.5

SUMMARY

Fluctuations in wireworm infestations have been observed for four seasons under a variety of crop rotations.

Plots containing alfalfa and with low initial populations showed a gradual though significant increase in the number of wireworms during the 4-year period.

Abnormal conditions for wireworm survival may be developed through the growing of red clover or through the intensive drying out of the soil. The former results in rapid increases in the number of wireworms. The drying of the soil was partially obtained through the growing of unirrigated wheat, in which case decreases exceeding 50 percent of the wireworms resulted in one season.

In the instance of late truck crops where a dry mulch was maintained during much of the season of beetle flight, the infestation has remained about stationary.

The only significant effect upon the infestations under pasture-sod conditions has been the reduction of the population in a plot which had a high initial infestation.

Plots planted to sugar beets and general garden crops show an increase in number of wireworms fully as significant as that of alfalfa, although not so consistent. The variation in the crops included in this rotation may account for the irregularities.

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